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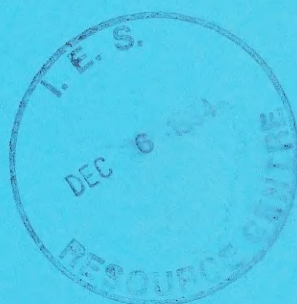


SEAWATER

A Library of MATLAB® Computational Routines for the Properties of Sea Water

Version 1.2

Phillip P. Morgan



1994

Earth Sciences Library

**CSIRO Marine Laboratories
Report 222**

SEAWATER

A Library of MATLAB[®] Computational Routines for the Properties of Sea Water

Version 1.2

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February 1994

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Preface

Scope of Document

This document describes how you can use the SEAWATER library of routines to calculate properties of sea water. The library is implemented in the MATLAB[®] language version 4. It is assumed you are familiar with physical oceanography and only a novice user of MATLAB or other programming languages. SEAWATER is essentially a computational package for oceanographers who may have little experience in using programming languages.

MATLAB[®] is a trademark of The MathWorks Inc. 24 Prime Park Way, Natick, Mass. 01760.

Acknowledgments

Thanks to Dr Steve Rintoul for granting the time and resources to develop this library; to Dr Nathan Bindoff for supplying the routines `sw_alpha`, `sw_beta` and `sw_aonb`, and to Drs David Jackett and John Wilkin for direction with `sw_bfrq`.

This work contributes to the CSIRO Climate Change Research Program, and is funded in part by Australia's National Greenhouse Research Program.

Errors and Suggestions

To uphold the integrity of the library, please report all errors and suggestions to me at the address below so that I can update the master set. When reporting errors, please record an actual session (use the diary command in MATLAB).

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1 Introduction

Many scientists have realised the value of "Fourth Generation Languages" such as MATLAB for carrying out data analysis. These languages enable scientists to concentrate on conducting research without worrying about the more technical aspects of computing.

SEAWATER is a library of MATLAB computational routines for determining properties of sea water that are commonly used in oceanographic research. It is of the utmost importance that these determinations are accurate. The driving force for developing this library was the need for an easy to use, set of routines that had been thoroughly tested. The SEAWATER library can be used on any computer platform that supports MATLAB. No recompiling or conversion is necessary.

MATLAB automatically keeps track of missing or bad data with the Not-A-Number (NaN) feature, and the ability to use multidimensional data structures in calculations greatly adds to the simplicity and usefulness of the library. For example, it is a simple matter to calculate the density for an entire hydrographic section (salinity, temperature and pressure) that has missing/bad data in a one-line statement, by calling the SEAWATER library.

The SEAWATER library implements all the polynomial equations presented by Foffonoff and Millard (UNESCO 1983). Validation of the SEAWATER library against the UNESCO results is demonstrated in Appendix C. A number of additional oceanographic properties, not described in the UNESCO report, are supported in the SEAWATER library and are described below.

1.1 Potential Density

Sea water is slightly compressible, which means that a sample of water brought from a depth to the surface will expand and therefore be cooler than it was in situ. The term "potential temperature" refers to the temperature of the sample of water at the surface if brought to the surface adiabatically. Similarly, "potential density" refers to the density of this water sample at the surface (Pond and Pickard 1986). The more general case is for a sample of water to be brought to a specified "reference" depth.

The potential density (ρ_θ) of sea water relative to a reference pressure (P_r) is a function of in situ salinity (S) and the potential temperature (θ), given by

$$\rho_\theta = \rho(S, \theta, P_r) \quad [\text{kg m}^{-3}].$$

This can be calculated by passing the reference pressure and the in situ salinity, temperature and pressure to the routine `sw_pden`,

$$\text{pden} = \text{sw_pden}(S, T, P, \text{PR}).$$

The potential density anomaly (σ_θ) is simply given by

$$\sigma_\theta = \rho_\theta - 1000.$$

1.2 Thermal Expansion and Saline Contraction

Polynomial expressions for the thermal expansion coefficient (α) and saline contraction coefficient (β) were defined by McDougall (1987). The polynomial expressions for α , β , and α/β have been implemented in routines `sw_alpha`, `sw_beta` and `sw_aonb` respectively. Check values from McDougall (1987) have been included in the on-line documentation.

1.3 Gravitational Acceleration and Coriolis Factor

Gill (1982) extended the UNESCO (1983) equation for the gravitational acceleration (g) as a function of latitude (ϕ) to include the radius of the Earth (a) and the variation with depth below sea surface (z),

$$g = (9.78032 + 0.005172 \sin^2 \phi - 0.00006 \sin^2 2\phi)(1 + z/a) \quad [\text{m s}^{-2}].$$

The expression for the Coriolis factor (f) is defined in Pond and Pickard (1986) by

$$f = 2\Omega \sin \phi \quad [\text{s}^{-1}],$$

where the rotation of the Earth is given by $\Omega = 7.29 \times 10^{-5} \text{ s}^{-1}$. The routines `sw_g` and `sw_f` evaluate the above two equations.

1.4 Distance in Latitude, Longitude Coordinates

The rhumb line or plain sailing method (Gormley 1989) is used to estimate the distance (d) between two positions on the earth's surface in latitude (ϕ) and longitude (θ) coordinates by the equation

$$d = 60\sqrt{(\Delta\phi)^2 + (\Delta\theta \cos\phi_{av})^2} \quad [\text{n.miles}],$$

where ϕ_{av} is the mean latitude, and the constant "60" converts to nautical mile units. The routine `sw_dist` can be used to evaluate distance.

1.5 Geostrophic Velocity

The concept of geostrophic velocity is well covered by Pond and Pickard (1986). The geostrophic velocity at a level (V_1) relative to a lower level (V_2) between two stations denoted by A and B is estimated by

$$V_1 - V_2 = \frac{(\Delta\Phi_B - \Delta\Phi_A)}{2d\Omega \sin\phi_{ave}} \quad [\text{m s}^{-1}],$$

where d is the distance between stations and the geopotential anomaly ($\Delta\Phi$) is the integral of the specific volume anomaly (δ),

$$\Delta\Phi = \int_{P_1}^{P_2} \delta dp \quad [\text{J kg}^{-1}].$$

If we traverse the section from station A to station B, a positive velocity is directed to the left of the path, whereas a negative velocity is directed to the right. This convention holds in both the northern and southern hemispheres, since southern latitudes span 0 to -90 degrees, which accounts for the different direction of the Coriolis force in the two hemispheres.

Evaluation of geostrophic velocities, relative to the sea surface, requires two steps in calling the SEAWATER routines:


```
gpan = sw_gpan(S,T,P)
gvel = sw_gvel(gpan,lat,lon)
```

Chapter 4 has an example of how to convert this velocity to a velocity relative to an arbitrary "reference" depth.

1.6 Buoyancy (Brunt-Väisälä) Frequency

The concept of stability is well covered by Gill (1982). The buoyancy frequency (N), also called the Brunt-Väisälä frequency, can be expressed (Jackett and McDougall, 1994) as a function of potential density (ρ_θ) by

$$N^2 = \frac{-g}{\rho_\theta} \frac{d\rho_\theta}{dz} \quad [\text{s}^{-2}].$$

The square of the buoyancy frequency is evaluated by the routine `sw_bfrq`.

Other methods for evaluating buoyancy frequency are discussed in (Millard et al. 1990); they are not used by the SEAWATER library.

2 Overview

2.1 Components of Library

The routines are designed to run on any computer that can run MATLAB, which includes MS-DOS PC, Mac, VAX and Unix machines. The names of routines are restricted to eight characters to be consistent with MS-DOS filename limitations. They are also prefixed by `sw_`, which denotes SEAWATER library routines, to delineate them from other routines that you may have. For example, the routine to calculate density is called "`sw_dens.m`".

The design of this library was for an extensible set of routines based on Software Engineering principles. Routine names and input parameter names are consistent, input parameters are not modified by the routines, and all routines have extensive on-line documentation and have been thoroughly tested. One advantage in this design is that the SEAWATER library forms a toolbox around which you may write further applications. This approach warrants splitting code into modules for easy development, testing and maintenance.

2.2 Brief Description of All Routines

A brief description of each routine in the SEAWATER library can be obtained by issuing the command `sw_info`.

ROUTINE	DESCRIPTION
SW_ALPHA	Thermal expansion coefficient (alpha)
SW_ADTG	Adiabatic temperature gradient
SW_AONB	Calculate alpha/beta (a on b)
SW_BETA	Saline contraction coefficient (beta)
SW_BFRQ	Brunt-Vaisala frequency (N^2)
SW_C3515	Conductivity at (35,15,0)
SW_CNDR	Conductivity ratio $R = C(S,T,P)/C(35,15,0)$
SW_CP	Heat capacity (C_p) of sea water
SW_DENS	Density of sea water
SW_DENS0	Density of sea water at atmospheric pressure
SW_DIST	Distance between two lat, lon coordinates
SW_DPTH	Depth from pressure
SW_F	Coriolis factor "f"
SW_FP	Freezing point of sea water
SW_G	Gravitational acceleration
SW_GPAN	Geopotential anomaly

SW_GVEL	Geostrophic velocity
SW_INFO	Information on the SEAWATER library.
SW_PDEN	Potential density
SW_PRES	Pressure from depth
SW_PTMP	Potential temperature
SW_SALDS	Differential $dS/d(\text{sqrt}(Rt))$ at constant T.
SW_SALRP	Conductivity ratio $R_p(S,T,P) = C(S,T,P)/C(S,T,0)$
SW_SALRT	Conductivity ratio $r_t(T) = C(35,T,0)/C(35,15,0)$
SW_SALS	Salinity of sea water
SW_SALT	Salinity from cndr, T, P
SW_SECK	Secant bulk modulus (K) of sea water
SW_SVAN	Specific volume anomaly
SW_SVEL	Sound velocity of sea water
SW_SMOW	Density of standard mean ocean water (pure water)
SW_TEMP	Temperature from potential temperature

2.3 Units of Data

The units of all properties are clearly defined in each routine. The units of pressure and depth need special attention. Pressure (in decibars) and depth (in meters) are taken to be zero at the sea surface and positive in the interior of the ocean. The routines `sw_pres` and `sw_depth` can be used to convert between pressure and depth. If you wish to use Cartesian coordinates with x,y,z representing East, North and height above sea surface respectively, then $\text{depth} = -z$.

The convention used for the units of latitude are decimal degrees ranging from -90 (South) to +90 (North). The units of longitude are decimal degrees ranging from -180 (180 West) to +180 (180 East).

2.4 Special Attention to the Temperature Scale

The polynomials for the equation of state (UNESCO 1983) were derived using the International Practical Temperature Scale of 1968 (IPTS-68). All routines in the SEAWATER library also use IPTS-68. The recommended conversion from the International Temperature Scale of 1990 (ITS-90) to IPTS-68 (UNESCO 1991) is the linear relationship $T_{68} = 1.00024 \times T_{90}$.

2.5 Testing Library for Accuracy

A comparison of results produced by the SEAWATER library with those tabulated by UNESCO (1983) are presented in Appendix C. It should be

remembered that these routines are only valid with temperature in the range -2 to 35 °C, and salinity in the range 2 to 42 psu (UNESCO 1983).

Not all routines are explicitly provided with test results, since many routines call other (lower-level) routines. A correct result at the higher level therefore verifies the lower-level routines as well.

2.6 Call Definitions for Routines

Property	Function calling template	Units
Adiabatic Temperature Gradient	adtg = sw_adtg(sal,temp,pres)	°C db ⁻¹
Saline Contraction	beta = sw_beta(salt,ptmp,pres)	psu ⁻¹
Conductivity	cond = cndr*sw_c3515	mS cm ⁻¹
Conductivity Ratio	cndr = sw_cndr(salt,temp,pres)	
Heat Capacity	cp = sw_cp(salt,temp,pres)	J kg ⁻¹ °C ⁻¹
Density	dens = sw_dens(salt,temp,pres)	kg m ⁻³
Distance	dist = sw_dist(lat,lon)	n.miles
Depth	dpth = sw_dpth(press,lat)	meters
Freezing Point	fp = sw_fp(salt,pres)	°C (IPTS68)
Geopotential Anomaly	gpan = sw_gpan(salt,temp,press)	J kg ⁻¹
Geostrophic Velocity	gvel = sw_gvel(gpan,lat,lon)	m s ⁻¹
Potential Density	pden = sw_pden(salt,ptmp,pres)	kg m ⁻³
Potential Temperature	ptmp = sw_ptmp(salt,temp,pres,ref_pres)	°C
Salinity	salt = sw_salt(cond,temp,pres)	psu (PPS78)
Sigma_t	sigt = sw_dens(salt,temp,zeros(salt)) - 1000	kg m ⁻³
Specify Volume Anomaly	svan = sw_svan(dens)	m ³ kg ⁻¹

3 Getting Started

The SEAWATER library is accessed within MATLAB so you will need to issue the appropriate command to start MATLAB on your system. The SEAWATER library can be installed in any directory but to see whether you have the correct access, type `sw_info` for information on the library. If you get an error message, check that you have the correct paths. See Appendix A for installation procedures.

3.1 Calling the SEAWATER routines.

Each routine in the SEAWATER library has a list of input parameters and output parameters. The general format is:

$$[\text{output_parameters}] = \text{sw_????}(\text{input_parameters}),$$

where `????` is a placeholder for the name of the particular routine.

To call a routine you must enter data in the order specified in the help display for each command. For example, the call for `sw_fp` is defined in the help display as `fp = sw_fp(S,P)`. To find the freezing point (fp) of sea water with a salinity (S) of 35.203 psu at a pressure (P) of 5.5 db is easily achieved by entering the command

```
>> fp = sw_fp(35.203,5.5)
fp =
    -1.9381
```

The convention used in this document is to show commands that you enter into MATLAB with the MATLAB prompt `'>> '` as a prefix. Do not enter this prefix in your commands. The output from MATLAB will be shown on lines without this prefix. In the above example, the result is assigned to the variable called "fp" on the command line. MATLAB echoes the result to the screen as shown. The echoing of results can be disabled by ending the line with a semicolon, as in the example below where the depth (d) corresponding to a pressure of 200 db at a latitude of 45 degrees is evaluated using `sw_dpth`:

```
>> p    = 200.5;
>> lat  = 45.5;
>> d    = sw_dpth(p,lat); % result is d = 198.7668
```


You may assign the data to named variables such as `p` and `lat` as shown in this example before passing to routines in the SEAWATER library.

3.2 Using Multidimensional data

MATLAB uses the two-dimensional data structure called a matrix (or 2D array) to store variables. An $M \times N$ matrix contains M rows and N columns. In special cases, one or both dimensions are one. A $1 \times N$ matrix is called a row vector, $M \times 1$ a column vector and a 1×1 matrix a scalar. The SEAWATER library is designed to handle all of these data structures.

For example, if we wish to find the corresponding freezing point for sea water at salinities 35.1, 35.2 and 35.3 at pressures of 10, 20 and 30 db respectively, it is a simple matter of defining the data and calling the routine:

```
>> s = [35.1 35.2 35.3];
>> p = [10 20 30];
>> fp = sw_fp(s,p)
fp =
    -1.9356    -1.9488    -1.9621
```

Generally, the input variables need to have the same dimensions, but there are some convenient alternatives that are described in the documentation for each routine. Pressure is often a parameter that has more flexible shape constraints. An example is evaluating the freezing point of sea water at the sea surface over a range of salinities from 33 to 36 psu at increments of 0.1 psu:

```
>> s = [33:0.1:36];
>> p = 0;
>> fp = sw_fp(s,p)
fp =
Columns 1 through 7
    -1.8079    -1.8136    -1.8193    -1.8250    -1.8307    -1.8364
-1.8421 Columns 8 through 14
    -1.8479    -1.8536    -1.8593    -1.8650    -1.8707    -1.8764
-1.8822 Columns 15 through 21
    -1.8879    -1.8936    -1.8994    -1.9051    -1.9108    -1.9166
-1.9223 Columns 22 through 28
    -1.9280    -1.9338    -1.9395    -1.9453    -1.9510    -1.9568
-1.9625 Columns 29 through 31
    -1.9683    -1.9741    -1.9798
```

Data in 2D arrays are just as easy to use in calculations:

```
>> s = [35.1 35.2 35.3;  
        35.0 35.1 35.2;  
        34.9 35.0 35.1];  
>> p = 0  
>> fp = sw_fp(s,p)  
fp =  
-1.9280 -1.9338 -1.9395  
-1.9223 -1.9280 -1.9338  
-1.9166 -1.9223 -1.9280
```


4 Tutorial for Oceanographers

4.1 Data for Tutorial

In oceanography, one often needs to process data that are part of a hydrographic section which generally involves temperature and salinity measurements of sea water at various depths. A simple example of this type of data is presented in Appendix B.

A file named `sw_data.mat` is supplied with the SEAWATER library where the variable named "temp" and "sal" define temperature and salinity, respectively on 32 pressures at 14 stations. The locations of the 14 stations are specified in the variables "lat" and "lon". You may wish to copy this file from the installation directory to your working directory and load the data by typing the command `load sw_data` and displaying the variable names with the `whos` command, as shown:

```
>> load sw_data
>> whos
```

Name	Size	Elements	Bytes	Density	Complex
bottom	1 by 14	14	112	Full	No
lat	1 by 14	14	112	Full	No
lon	1 by 14	14	112	Full	No
press	32 by 1	32	256	Full	No
sal	32 by 14	448	3584	Full	No
temp	32 by 14	448	3584	Full	No

Grand total is 1051 elements using 8408 bytes

The data in the file `sw_data` were imported from another application wherein missing data were represented with a -99 flag in the temperature and salinity fields. To take advantage of MATLAB's automatic handling of missing data, it is necessary to convert the -99 flag to NaN. The following commands will do this:

```
ibad = find(temp<-90);
temp(ibad) = NaN*ones(size(ibad));
ibad = find(sal <-90);
sal(ibad) = NaN*ones(size(ibad));
```

Taking station number 5 as an example, the temperature and salinity profiles can be plotted and labelled (Figures 1 and 2) by using the following MATLAB commands:

```
plot(press,temp(:,5),'o')
hold on
```

```

plot(press,temp(:,5),'-')
hold off
title('Temperature Profile for Stations 5')
xlabel('Pressure (db) ')
ylabel('Temp (C) ')

plot(press,sal(:,5),'o'); hold on
plot(press,sal(:,5),'-'); hold off
title('Salinity Profile for Stations 5')
xlabel('Pressure (db) '); ylabel('Sal (psu) ')

```

Fig 1: Temperature Profile for Station 5

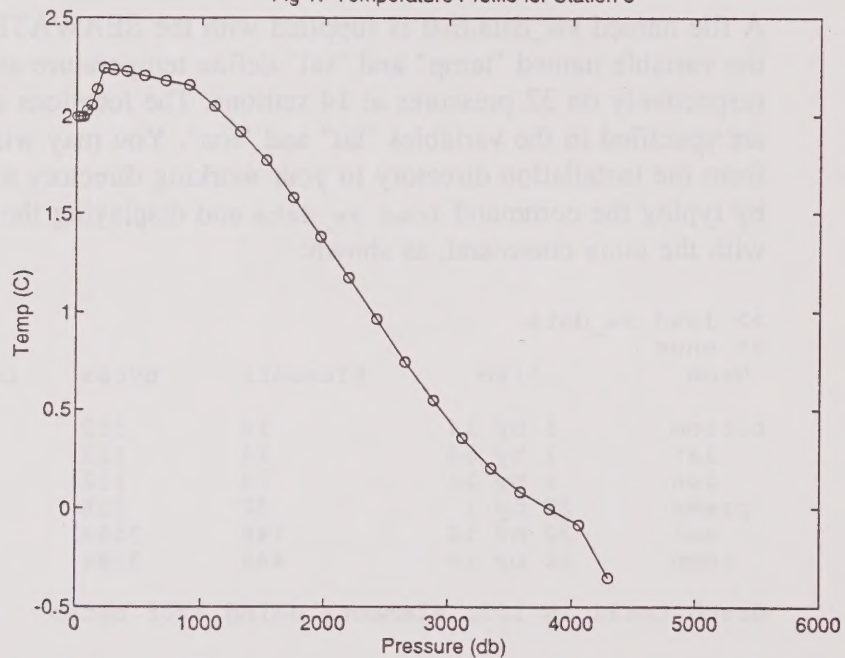
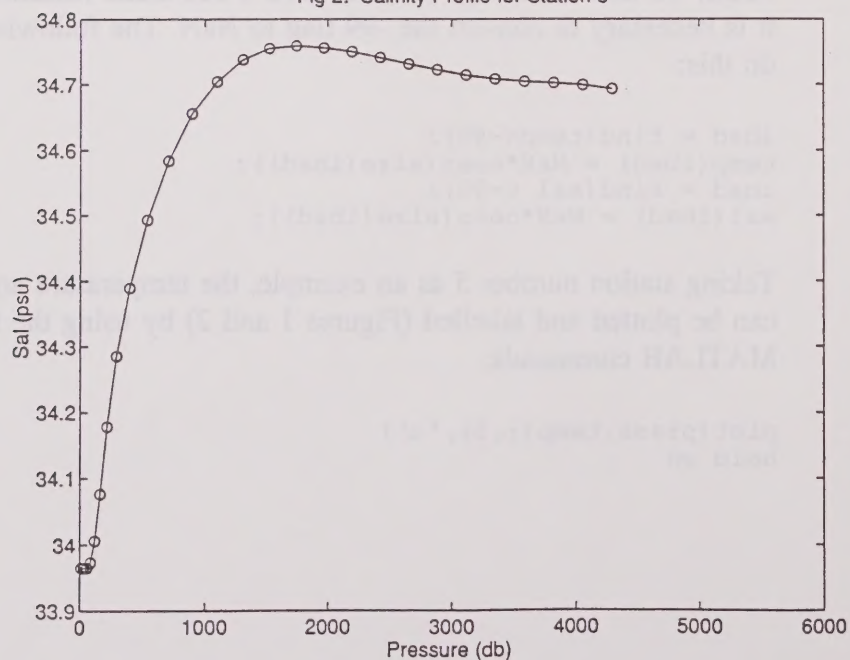


Fig 2: Salinity Profile for Station 5



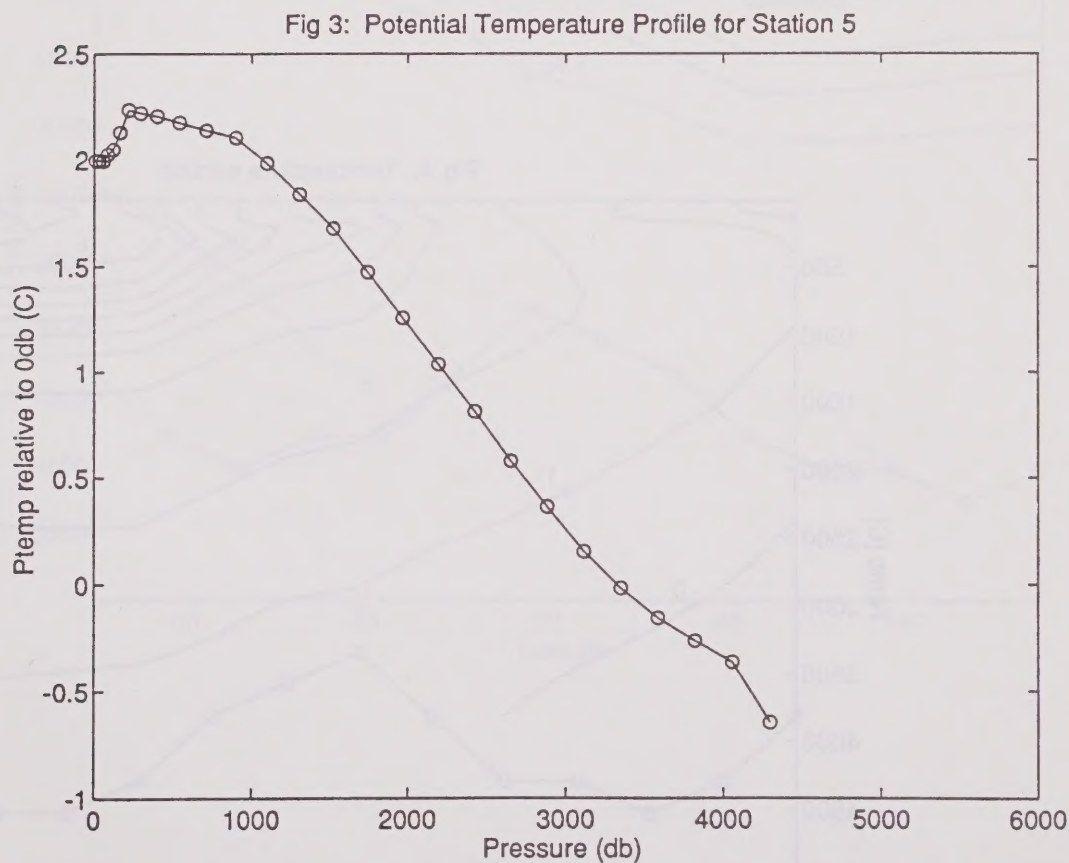
4.2 Potential Temperature Profile

The potential temperature, relative to the sea surface, for station 5 can be calculated by using the data for station 5 as follows:

```
ptmp5 = sw_ptmp(sal(:,5),temp(:,5),press,0);
```

The potential temperature profile (Figure 3) for station 5 was constructed using the following commands,

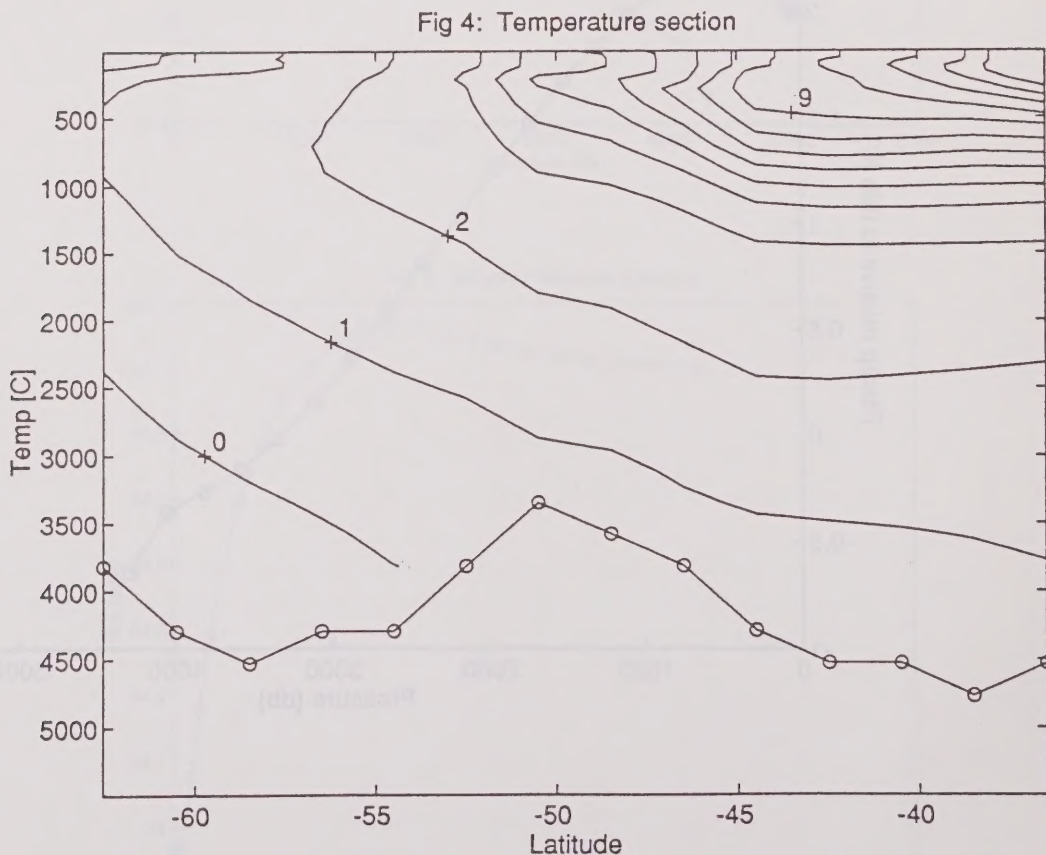
```
plot(press,ptmp5,'o')  
hold on  
plot(press,ptmp5,'-')  
hold off  
title('Potential Temperature Profile for Stations 5')  
xlabel('Pressure (db) ')  
ylabel('Pot. Temp. rel P=0 (C) ')
```



4.3 Contour Plot of Temperature, Salinity and Density

Contouring of derived properties for the entire section is also a simple matter in MATLAB. For example, contour sections for temperature (Figure 4) at intervals of 1 degree and salinity (Figure 5) at intervals of 0.1 psu with bottom topography can be generated with the following MATLAB commands:

```
contlevs = [-1:1:13];
cs = contour(lat,press,temp,contlevs);
title('Temperature section')
xlabel('Latitude')
ylabel('Temp [C]')
axis('ij')
clabel(cs,'manual')
% plot bottom
hold on
plot(lat,bottom,'o')
plot(lat,bottom,'-')
hold off
```

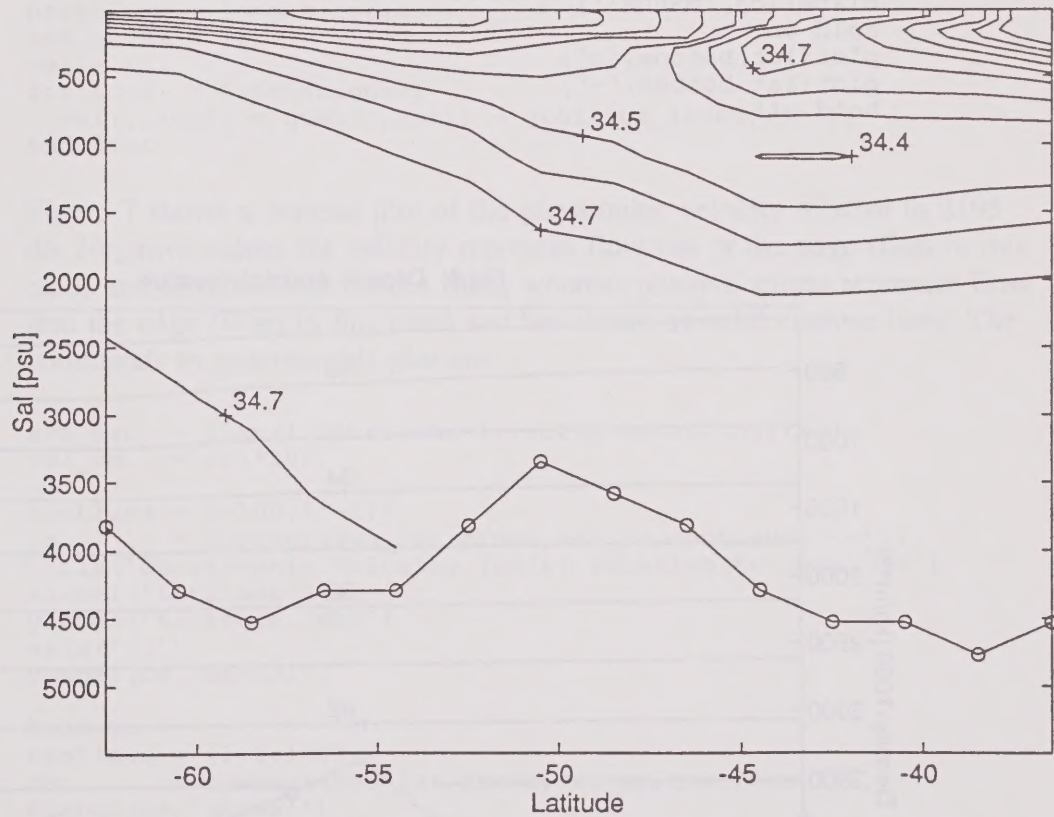



```

contlevs = [33.8:0.1:35.2];
cs = contour(lat,press,sal,contlevs);
title('Salinity section')
xlabel('Latitude')
ylabel('Sal [psu]')
axis('ij')
clabel(cs,'manual')
hold on
plot(lat,bottom,'o')
plot(lat,bottom,'-')
hold off

```

Fig 5: Salinity section

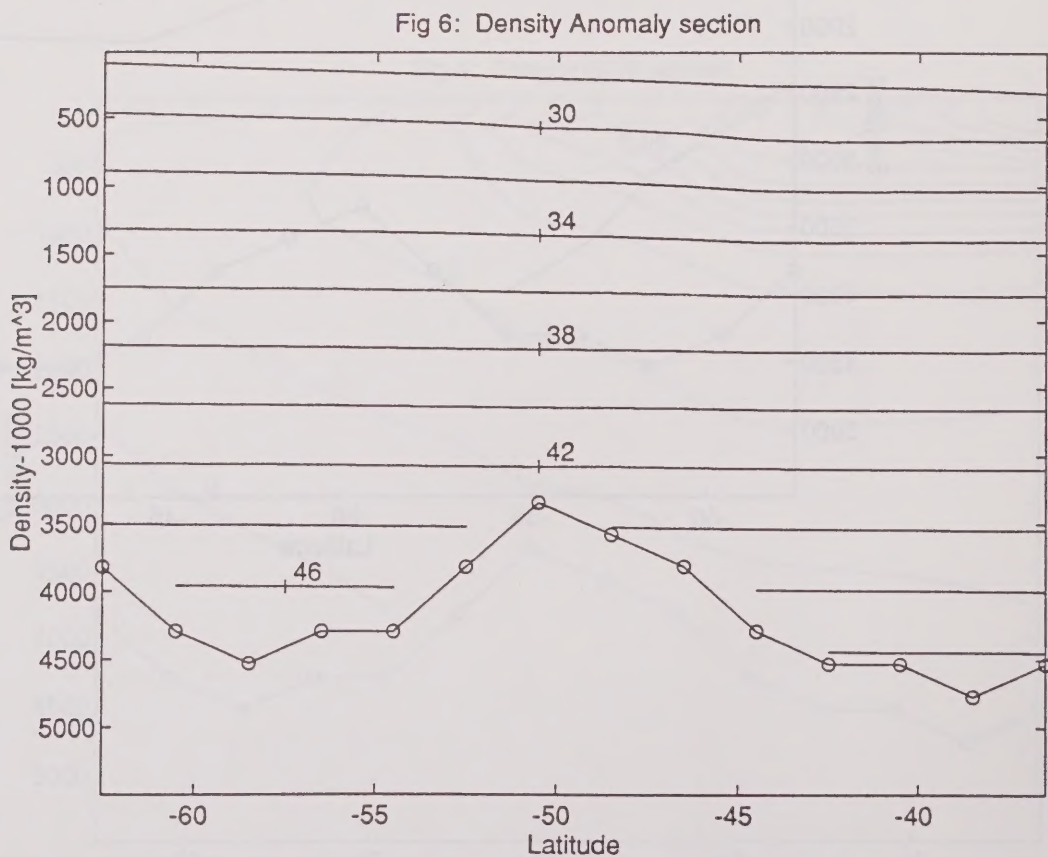


The density for the entire section can be calculated with the single command:

```
dens = sw_dens(sal,temp,press);
```

The contour section for density anomaly is readily displayed (Figure 6) with the commands:

```
contlevs = [26:2:50];
cs = contour(lat,press,dens-1000,contlevs);
title('Density Anomaly section')
xlabel('Latitude')
ylabel('Dens-1000 [kg/m^3]')
axis('ij')
clabel(cs,'manual')
hold on
plot(lat,bottom,'o')
plot(lat,bottom,'-')
hold off
```



4.4 Geostrophic Velocity

A frequent objective in oceanography is to calculate the geostrophic velocity relative to the sea surface. The routine `sw_gvel` requires the geopotential anomaly, so an intermediate step is needed. This can be achieved in two separate commands or you may combine the steps into one command:

```
gpan = sw_gpan(sal,temp,press);
gvel = sw_gvel(gpan,lat,lon);
% or
gvel = sw_gvel( sw_gpan(sal,temp,press) , lat,lon);
```

The geostrophic velocity relative to the 18th pressure level (2195 db) is given by:

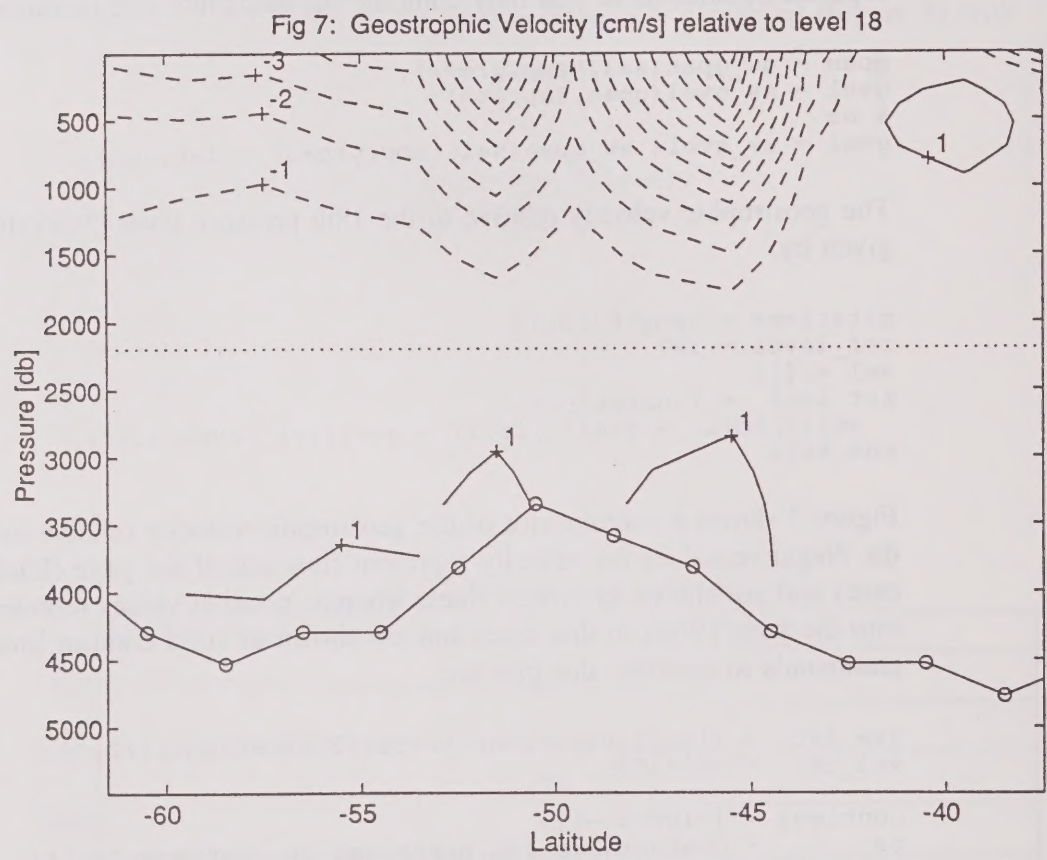
```
nstations = length(lat);
ref_level = 18;
vel = [];
for icol = 1:nstations-1
    vel(:,icol) = gvel(:,icol) - gvel(ref_level,icol);
end %for
```

Figure 7 shows a contour plot of the geostrophic velocity relative to 2195 db. Negative values for velocity represent flow out of the page (East in this case) and are shown as broken lines, whereas positive values represent flow into the page (West in this case) and are shown as solid contour lines. The commands to generate this plot are:

```
ave_lat = (lat(1:nstations-1)+lat(2:nstations))/2;
vel_cm = vel*100;

contlevs = [-100:1:-1];
cs = contour(ave_lat,press,vel_cm,contlevs,'--');
title('Geostrophic Velocity [cm/s] relative to level 18')
xlabel('Latitude')
ylabel('Pressure [db]')
axis('ij')
clabel(cs,'manual')

hold on
contlevs = [1:1:100];
cs = contour(ave_lat,press,vel_cm,contlevs,'-');
clabel(cs,'manual')
plot(lat,press(ref_level)*ones(size(lat)),':')
plot(lat,bottom,'o')
plot(lat,bottom,'-')
hold off
```



References

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Appendix A. Distribution and Installation

The SEAWATER library can be obtained by anonymous ftp to [ftp.ml.csiro.au](ftp://ml.csiro.au) (192.67.12.100). All the files are in the directory named `/pub/morgan/seawater`.

The SEAWATER library can be installed in any directory but you must have the appropriate path set in MATLAB; see the MATLAB command `help path` for instructions. However, the best place to install the SEAWATER library is in the "local" directory recommended by MathWorks for user-contributed routines.

Appendix B. Example Hydrographic Dataset

A simplified example of oceanographic data is presented to aid in using the SEAWATER library for oceanographic applications. The following data represent a hydrographic section where temperature and salinity data are shown for 14 stations at 32 depths (actually pressure in the units of decibars). The stations lie on a meridional section along 117°E at intervals of 2.5 degrees. Station number 1 is located at latitude 62.5°S (near Antarctica) and station number 14 at latitude 36.5°S (near Australia).

The data equally well represent measured hydrographic data or the output from numerical models. The dataset is used throughout the tutorial in Section 4. Missing or bad data, a common problem in data analysis, have been denoted by flag values of -99.000. The data presented on the next two pages are available in the MATLAB file `sw_data.m` in the SEAWATER library.

(db)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
10	34.058	34.039	34.014	33.986	33.965	33.979	34.060	34.131	34.258	34.472	34.624	34.722	34.947	35.514
33	34.096	34.055	34.014	33.986	33.965	33.979	34.060	34.110	34.256	34.472	34.624	34.722	34.947	35.514
58	34.175	34.102	34.026	33.986	33.965	33.979	34.060	34.107	34.256	34.472	34.624	34.722	34.947	35.514
87	34.271	34.170	34.060	34.002	33.973	33.979	34.060	34.107	34.253	34.473	34.699	34.817	34.947	35.510
121	34.378	34.271	34.131	34.047	34.006	33.996	34.060	34.112	34.253	34.473	34.738	34.881	35.040	35.484
163	34.481	34.395	34.241	34.130	34.076	34.073	34.136	34.131	34.251	34.633	34.749	34.904	35.116	35.406
218	34.569	34.523	34.387	34.258	34.178	34.168	34.263	34.311	34.297	34.726	34.733	34.879	35.088	35.300
292	34.639	34.616	34.498	34.376	34.285	34.259	34.319	34.363	34.528	34.757	34.733	34.823	34.957	35.169
397	34.694	34.678	34.585	34.480	34.389	34.350	34.365	34.394	34.532	34.738	34.687	34.727	34.792	34.939
537	34.716	34.717	34.657	34.577	34.493	34.423	34.410	34.421	34.511	34.682	34.641	34.646	34.658	34.715
707	34.734	34.741	34.708	34.654	34.583	34.529	34.450	34.428	34.455	34.561	34.547	34.559	34.562	34.584
896	34.733	34.747	34.737	34.707	34.655	34.601	34.504	34.477	34.430	34.437	34.438	34.454	34.461	34.465
1099	34.730	34.747	34.750	34.738	34.704	34.658	34.560	34.528	34.459	34.397	34.395	34.414	34.429	34.436
1309	34.723	34.742	34.755	34.754	34.738	34.708	34.634	34.607	34.537	34.449	34.449	34.470	34.488	34.499
1525	34.717	34.736	34.755	34.761	34.755	34.737	34.684	34.664	34.608	34.522	34.518	34.537	34.563	34.584
1746	34.709	34.728	34.747	34.758	34.759	34.750	34.716	34.704	34.665	34.600	34.604	34.619	34.639	34.650
1969	34.706	34.721	34.737	34.750	34.756	34.755	34.738	34.733	34.710	34.669	34.673	34.682	34.692	34.699
2195	34.704	34.714	34.727	34.740	34.750	34.754	34.749	34.748	34.742	34.717	34.717	34.720	34.725	34.730
2423	34.700	34.708	34.719	34.731	34.741	34.747	34.749	34.751	34.754	34.743	34.741	34.742	34.744	34.745
2653	34.696	34.702	34.712	34.722	34.731	34.737	34.744	34.748	34.753	34.753	34.752	34.752	34.753	34.753
2884	34.693	34.698	34.705	34.714	34.722	34.727	34.737	34.740	34.748	34.754	34.755	34.756	34.757	34.757
3116	34.691	34.695	34.700	34.708	34.714	34.719	34.729	34.731	34.743	34.750	34.753	34.755	34.757	34.758
3350	34.689	34.692	34.698	34.703	34.708	34.713	34.720	34.723	34.737	34.744	34.747	34.750	34.754	34.758
3585	34.688	34.691	34.696	34.701	34.704	34.707	99.000	34.718	34.731	34.736	34.739	34.743	34.749	34.755

Appendix C. Test Report

```

*****
*          TEST REPORT          *
*                               *
*   SEA WATER LIBRARY   *
*                               *
*   Version 1.2         *
*                               *
*   13-Jan-94          *
*****

```

```

*****
** TESTING MODULE: sw_ptmp
** and SUB-MODULE: sw_adtg.m
*****

```

```

*****
Comparison of accepted values from UNESCO 1983
(Unesco Tech. Paper in Marine Sci. No. 44, p45)
with computed results from sw_ptmp on SUN4 computer
*****

```

Sal (psu)	Temp (C)	Press (db)	PTMP (C)	sw_ptmp (C)
25	0	0	0.0000	0.00000
25	10	0	10.0000	10.00000
25	20	0	20.0000	20.00000
25	30	0	30.0000	30.00000
25	40	0	40.0000	40.00000

Sal (psu)	Temp (C)	Press (db)	PTMP (C)	sw_ptmp (C)
25	0	5000	-0.3061	-0.30614
25	10	5000	9.3531	9.35306
25	20	5000	19.0438	19.04376
25	30	5000	28.7512	28.75125
25	40	5000	38.4607	38.46068

Sal (psu)	Temp (C)	Press (db)	PTMP (C)	sw_ptmp (C)
35	0	0	0.0000	0.00000
35	10	0	10.0000	10.00000
35	20	0	20.0000	20.00000
35	30	0	30.0000	30.00000
35	40	0	40.0000	40.00000

Sal (psu)	Temp (C)	Press (db)	PTMP (C)	sw_ptmp (C)
35	0	5000	-0.3856	-0.38556
35	10	5000	9.2906	9.29064
35	20	5000	18.9985	18.99845
35	30	5000	28.7231	28.72314
35	40	5000	38.4498	38.44980


```

*****
** TESTING MODULE: sw_svan.m
** and SUB-MODULE: sw_dens.m sw_dens0.m sw_smow.m sw_seck.m
**                  sw_pden.m sw_ptmp.m
*****

```

```

*****
Comparison of accepted values from UNESCO 1983
(Unesco Tech. Paper in Marine Sci. No. 44, p22)
with computed results from sw_svan.m on SUN4 computer
*****

```

Sal (psu)	Temp (C)	Press (db)	SVAN ($1e-8 \text{ m}^3/\text{kg}$)	sw_svan ($1e-8 \text{ m}^3/\text{kg}$)
0	0	0	2749.54	2749.539
0	0	10000	2288.61	2288.610
0	30	0	3170.58	3170.582
0	30	10000	3147.85	3147.853
35	0	0	0.00	0.000
35	0	10000	0.00	0.000
35	30	0	607.14	607.142
35	30	10000	916.34	916.336

```

*****
** TESTING MODULE: sw_salt.m
** and SUB-MODULE: sw_salrt.m sw_salrp.m sw_sals.m
*****

```

```

*****
Comparison of accepted values from UNESCO 1983
(Unesco Tech. Paper in Marine Sci. No. 44, p9)
with computed results from sw_salt.m on SUN4 computer
*****

```

Temp (C)	Press (db)	R (no units)	S (psu)	sw_salt (psu)
15	0	1.00	35.000000	34.9999999
20	2000	1.20	37.245628	37.2456277
5	1500	0.65	27.995347	27.9953469

```
*****
** TESTING MODULE: sw_cndr.m
** and SUB-MODULE: sw_saldrs.m
*****
```

```
*****
Comparison of accepted values from UNESCO 1983
(Unesco Tech. Paper in Marine Sci. No. 44, p14)
with computed results from sw_cndr.m on SUN4 computer
*****
```

Temp (C)	Press (db)	S (psu)	cndr (no units)	sw_cndr (no units)
0	0	25.000000	0.498008	0.4980083
10	0	25.000000	0.654990	0.6549902
0	1000	25.000000	0.506244	0.5062444
10	1000	25.000000	0.662975	0.6629750
10	0	40.000000	1.000073	1.0000731
30	0	40.000000	1.529967	1.5299670

```
*****
** TESTING MODULE: sw_dpth.m
*****
```

```
*****
Comparison of accepted values from Unesco 1983
(Unesco Tech. Paper in Marine Sci. No. 44, p28)
with computed results from sw_dpth.m on SUN4 computer
*****
```

Lat (degree)	Press (db)	DPTH (meter)	sw_dpth (meter)
0.000	500	496.65	496.653
30.000	500	496.00	495.998
45.000	500	495.34	495.343
90.000	500	494.03	494.034

Lat (degree)	Press (db)	DPTH (meter)	sw_dpth (meter)
0.000	5000	4915.04	4915.041
30.000	5000	4908.56	4908.560
45.000	5000	4902.08	4902.081
90.000	5000	4889.13	4889.131

Lat (degree)	Press (db)	DPTH (meter)	sw_dpth (meter)
0.000	10000	9725.47	9725.471
30.000	10000	9712.65	9712.653
45.000	10000	9699.84	9699.841
90.000	10000	9674.23	9674.231


```
*****
**  TESTING MODULE: sw_fp.m
*****
```

```
*****
Comparison of accepted values from UNESCO 1983
(Unesco Tech. Paper in Marine Sci. No. 44, p30)
with computed results from sw_fp.m on SUN4 computer
*****
```

Sal (psu)	Press (db)	fp (C)	sw_fp (C)
5	0	-0.274	-0.2738
10	0	-0.542	-0.5425
15	0	-0.812	-0.8116
20	0	-1.083	-1.0832
25	0	-1.358	-1.3584
30	0	-1.638	-1.6379
35	0	-1.922	-1.9223
40	0	-2.212	-2.2121

Sal (psu)	Press (db)	fp (C)	sw_fp (C)
5	500	-0.650	-0.6503
10	500	-0.919	-0.9190
15	500	-1.188	-1.1881
20	500	-1.460	-1.4597
25	500	-1.735	-1.7349
30	500	-2.014	-2.0144
35	500	-2.299	-2.2988
40	500	-2.589	-2.5886

```
*****
**  TESTING MODULE: sw_cp.m
*****
```

```
*****
Comparison of accepted values from UNESCO 1983
(Unesco Tech. Paper in Marine Sci. No. 44, p37)
with computed results from sw_cp.m on SUN4 computer
*****
```

Sal (psu)	Temp (C)	Press (db)	Cp (J/kg.C)	sw_cp (J/kg.C)
25	0	0	4048.4	4048.44
25	10	0	4041.8	4041.83
25	20	0	4044.8	4044.84
25	30	0	4049.1	4049.10
25	40	0	4051.2	4051.22

Sal (psu)	Temp (C)	Press (db)	Cp (J/kg.C)	sw_cp (J/kg.C)
25	0	5000	3896.3	3896.26
25	10	5000	3919.6	3919.56
25	20	5000	3938.6	3938.60
25	30	5000	3952.0	3952.04
25	40	5000	3966.1	3966.11

Sal (psu)	Temp (C)	Press (db)	Cp (J/kg.C)	sw_cp (J/kg.C)
35	0	0	3986.5	3986.53
35	10	0	3986.3	3986.34
35	20	0	3993.9	3993.85
35	30	0	4000.7	4000.68
35	40	0	4003.5	4003.46

Sal (psu)	Temp (C)	Press (db)	Cp (J/kg.C)	sw_cp (J/kg.C)
35	0	5000	3849.3	3849.26
35	10	5000	3874.7	3874.73
35	20	5000	3895.0	3894.99
35	30	5000	3909.2	3909.24
35	40	5000	3923.9	3923.90

** TESTING MODULE: sw_svel.m

Comparison of accepted values from UNESCO 1983
(Unesco Tech. Paper in Marine Sci. No. 44, p50)
with computed results from sw_svel.m on SUN4 computer

Sal (psu)	Temp (C)	Press (db)	SVEL (m/s)	sw_svel (m/s)
25	0	0	1435.8	1435.79
25	10	0	1477.7	1477.68
25	20	0	1510.3	1510.31
25	30	0	1535.2	1535.21
25	40	0	1553.4	1553.45

Sal (psu)	Temp (C)	Press (db)	SVEL (m/s)	sw_svel (m/s)
25	0	5000	1520.4	1520.36
25	10	5000	1561.3	1561.31
25	20	5000	1593.6	1593.60
25	30	5000	1619.0	1618.96
25	40	5000	1638.0	1638.03

Sal (psu)	Temp (C)	Press (db)	SVEL (m/s)	sw_svel (m/s)
35	0	0	1449.1	1449.14
35	10	0	1489.8	1489.82
35	20	0	1521.5	1521.46
35	30	0	1545.6	1545.60
35	40	0	1563.2	1563.21

Sal (psu)	Temp (C)	Press (db)	SVEL (m/s)	sw_svel (m/s)
35	0	5000	1534.0	1533.97
35	10	5000	1573.4	1573.41
35	20	5000	1604.5	1604.48
35	30	5000	1629.0	1628.97
35	40	5000	1647.3	1647.30

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